CITIZEN SCIENCE: BRIDGING THE GAP BETWEEN PEOPLE AND POLICY

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Public Affairs

by

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May 2017

ABSTRACT

Citizen Science is an ever increasingly relevant societal tool employed to educate and motivate the populace in the ways and utility of science. Collaborative efforts benefit both the laity and academia, contributing to our body of scientific knowledge while creating opportunities to effect governmental policy changes. Investigations into perceived environmental problems especially issues surrounding clean water have mobilized legions of dedicated volunteer, amateur scientists to document the water quality of local streams and rivers. This paper reviews the work of three organizations that use citizen scientists to help gather data and assess the biological and chemical health of our public waterways. The groups investigated are: the Sierra Club New York Water Sentinels, the New York State Department of Environmental Conservation WAVE Program, and the Community Science Institute Red Flag and Benthic monitoring programs. Recommendations for ways in which Citizen Science can facilitate environmental (especially clean water) initiatives are provided.

BIOGRAPHICAL SKETCH

Joan Chu attended Prince George's Community College in Largo, Maryland with a concentration in general studies/ music. She matriculated to the University of Maryland, College Park in January 2010 and graduated with duel baccalaureates in *Government and Politics* and *Sociology,* in December 2013. Her environmental policy interests include issues of clean water, hydraulic fracturing impacts from oil and gas extraction, and environmental social justice.

ACKNOWLEDGEMENTS

I am especially grateful to my thesis advisor, Professor John Mathiason, for his encouragement and support, and to my program advisor Professor Huaizhu Oliver Gao. Thanks also to Alene Onion (NY Department of Environmental Conservation WAVE Program Coordinator), and Adrianna Hirtler (Community Science Institute Benthic Lab Director).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BMI	Benthic Macro-Invertebrates
CAISE	Center for Advancement of Informal Science Education
CLO	Cornell Laboratory of Ornithology
COND	Conductivity
CS	Citizen Science
CSI	Community Science Institute
CSI-RF	Community Science Institute – Red Flag Volunteers
EPA	Environmental Protection Agency
EU	European Union
NSF	National Science Foundation
NYS-DEC	New York State - Department of Environmental Conservation
SC-NYWS	Sierra Club – New York Water Sentinels
PPSR	Public Participation in Science Research
PUS	Public Understanding of Science
SAL	Salinity
SLPWA	Seneca Lake Pure Water Association
TDS	Total Dissolved Solids
T	Tolerance Value
WAVE	Water Assessment by Volunteer Evaluators

PREFACE

Issues of water quality and availability have pervaded the news for decades. The recent Lead contaminations to drinking water from Flint, Michigan to Ithaca, New York serve to highlight the concerns of the public for our shared water resources (Wang; O'Connor). As we anticipate the impacts of continued fossil fuel use concomitant with ongoing climate change and its associated rising seas, extreme weather events and compromises to water purity (from salinization, acidification, sedimentation and pollution), the necessity for remedies takes on a particular urgency. Citizens are uniquely poised to recognize the imminent water crises within their own communities and act to document and alleviate damage to the local environment. Individuals have a store of untapped knowledge about the surroundings where they live, work and recreate and so are perhaps best suited to monitor and care for our natural resources – from the ground up (Bonney & Shirk et al.). Citizen science can be an effective tool not only to effect policy changes in natural resource management but to promote a better understanding of science and scientific inquiry among the populace.

CITIZEN SCIENCE: BRIDGING THE GAP BETWEEN
PEOPLE AND POLICY

INTRODUCTION

Citizen science is a term simultaneously coined in 1995 by Britain Alan Irwin and American Rick Bonney (Irwin; Bonney, et al.; Cooper & Lewenstein). It defines the collaborative efforts of scientists and the public with the aims of 1) addressing citizen needs, 2) informing and educating the public on scientific endeavors, 3) engaging people in the development, data collection, and analysis of scientific research, and 4) motivating citizens in finding solutions to societal (especially environmental) concerns (Bonney & Ballard et al.; Shirk et al.).

Citizen science (CS) is a methodology whose recent origins belie its ancient roots. Literally as long as humans have walked the earth, we have been manipulating and testing our environment to work our will. Haklay suggests that the beginnings of experimentation occurred with the prehistoric hunter-gatherer societies as they learned to track prey, and 'read' the weather in anticipation of planting. This use of observation is an innately animal characteristic and humans have exploited it richly in the pursuit of scientific investigation. It's my belief that we are all scientists at heart, though most don't acknowledge it. Science performed by 'non-professionals' was in fact the norm up until the last centuries (Cohen; Cooper & Lewenstein). The contributions of many so-called amateurs and hobbyists have led to major advances in biology (Gregor Mendel, Charles Darwin), chemistry (Joseph Priestley), physics (Michael Faraday, Thomas Edison) and astronomy (William Herschel), to name but a few areas of scientific endeavor (Malone; Quammen; Rutgers; Couper & Henbest; Science Comm. Unit). Several of our Founding Fathers (*i.e.* Jefferson, Franklin, Adams, and Madison) were also amateur scientists and their devotion to scientific reasoning informed their political and governmental sensibilities (Cohen). It is not so big a leap then that today's citizen science efforts should seek to effect governmental change in the ways we utilize and steward our natural resources.

The way in which public participation in scientific research (PPSR) is manifest and varied and ranges along a continuum of public engagement. Shirk et al. propose five discrete categories of citizen involvement, from least participatory investment to most and described as follows:

- *Contractual Projects* – endeavors solicited by the public to researchers to answer community concerns;
- *Contributory Projects* – professionally designed research to which citizens can contribute data;
- *Collaborative Projects* – professionally designed research but with some additional input from citizens regarding project refinement, data analysis, and dissemination of results;
- *Co-created Projects* – research designed and executed by both citizens and scientists;
- *Collegial Contributions* – independent research projects by "non-credentialed", lay citizens

While I will utilize at least some of these categories in my descriptive report, more important to the success (or failure) of citizen science projects is the central question around which the inquiry revolves (Lindenmayer & Likens, Bonney & Cooper, et al.; Hochachka et al.). Both Bonney et al. and Shirk et al. maintain that a well-framed *question* is what makes or breaks public participation in scientific research. For this reason, I have chosen to focus on the concerns over water quality in our communities. The central/common question relevant to the programs that I have studied is:

Are the waters of New York State clean… and if not, how would we know it?

The purpose of this thesis is to review the argument that citizen science is a form of popular participation and civic engagement that bridges the Science-Policy divide by giving the public a direct way to influence the decision making process with regard to environmental policy (specifically water issues). Toward that end, I will first discuss the use of citizen science as an educational tool. Next I will review some threats to water quality that have served as prime motivators for public action. Lastly I will examine the missions of three citizen science organizations that utilize the contributory and collaborative project models previously defined and whose chosen focus is water quality. The groups are: the Sierra Club's New York Water Sentinels (SC-NYWS), the New York State - Department of Environmental Conservation (NYS-DEC) Water Assessment by Volunteer Evaluators (WAVE), and the Community Science Institute's (CSI) benthic and water chemistry monitoring programs. Other than published literature, my research informational sources include: direct observation of collection methods, investigation of online data/results (where available), attendance at workshops/conferences, and personal communications with organizational leaders and participants. This report will document collection procedures, sample results, and organizational accomplishments. It will also note the cross-pollination effect between groups and the potential to more directly influence lawmakers and governmental officials.

EDUCATING THE CITIZENRY

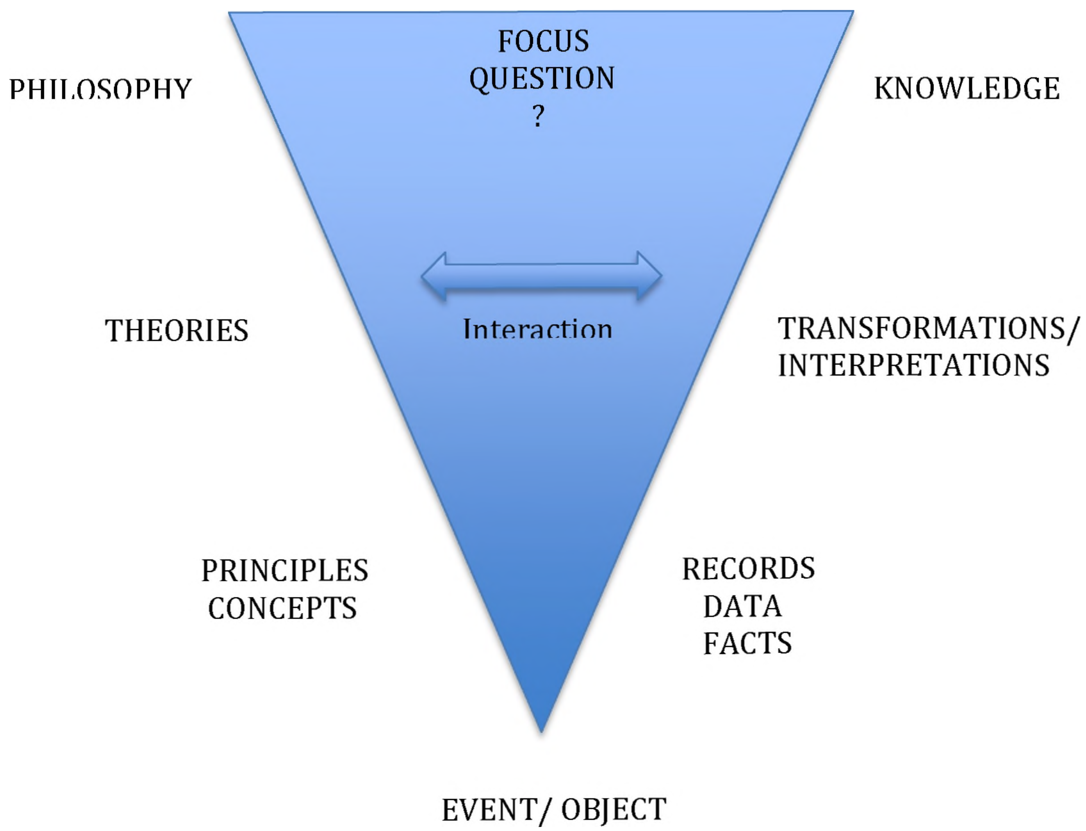
First and foremost citizen science is an educational tool. Ideally participants learn the use of scientific methods and the import of scientific inquiry in addressing real-world concerns (Bonney & Phillips et al.). Just how citizen-participants learn science is integral to the success and sustainability of any citizen science program so by way of further explanation we look to the learning theories of two Cornell professors, Joseph Novak and Bob Gowan.

Science, and in fact all learning is about asking questions and seeking answers. The study of learning, or how we know what we know is called *epistemology* and it is highly relevant to the essence of citizen science. In the 1970's and 80's, Novak and Gowan set forth their educational theories and ultimately published them in a book *Learning How to Learn.* Novak was interested in facilitating science learning and promoted 'hands-on' projects especially for young learners. He envisioned learning as a broad landscape of ideas and perspectives he called a "concept map." Bits of information connect to other bits and as we learn, our web of knowledge stretches far and wide. The more connections we make between things in our observable world, the deeper our knowledge. While book learning is important to understanding our world, *experiential* learning allows us to internalize that knowledge and has more lasting effect for the learner. The adage 'learn by doing' is certainly at play here, and is exemplified in the work of citizen science. It is likely because 'doing' relies on connections between both physical, muscle memory and cognitive memory that is has such staying power. Indeed in recent years psychologists have used this explanation in studies of 'gift-giving' satisfaction. Giving a gift of a shared activity or experience (movie, theater outing, concert, camping trip, dance party…) produces a more memorable and satisfying effect than the gifting of a 'thing' (Hamblin; Van Boven & Gilovich). Probably very few of us remembers what one thing we got for our 9th birthday, yes? For these same reasons the experience of actually 'doing' science holds more meaning and satisfaction for the citizen-participants.

Learning How to Learn also put forth Gowan's ideas of the ways in which understanding progresses from theory to actualization. His thinking is illustrated diagrammatically in what he termed an *Epistemological Vee* (Figure 1). Theoretical, conceptual underpinnings on the left flank of the Vee lead downhill to a specific event or observation which progresses back uphill through data analysis and interpretation to new understanding/knowledge on the right flank. Again, as with all science (and learning) it is a question (interior to the Vee) that focuses and directs our path to understanding.

Figure 1.
Epistemological Vee – Diagrammatic Representation of How Learning Occurs *from*

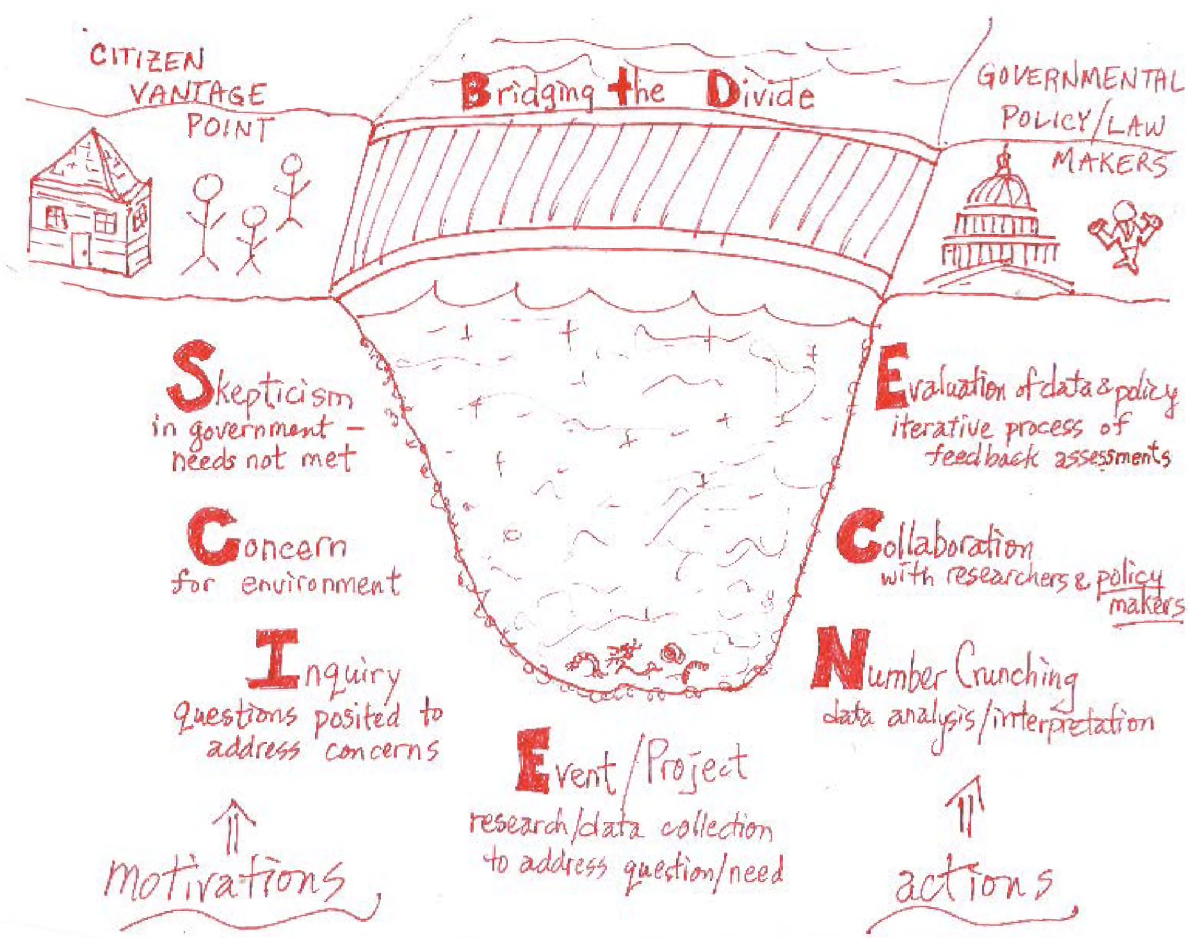
Novak, J. D. and Gowan, D. B. (1984). *Learning How to Learn.* New York, NY: Cambridge University Press.



To better frame the process of citizen science I have adapted Gowan's *Epistemological Vee* to describe its purpose and effect in Figure 2. The citizen science Vee is symbolic of a riverbed in cross-section. The world of the citizenry on the left shore starts from a place of skepticism and concern for water quality: *Are our waterways clean?* The event at the streambed bottom is a citizen science water-sampling project to discern the answer to the second part of the question: *If not, how would we know it?* Data analysis and interpretation on the right bank help inform appropriate potential policy decisions. All three of the citizen science organizations to be studied will be viewed in light of this citizen science Vee/model.

Figure 2.
Epistemological Vee – How Citizen Science can Inform Lawmakers/Policy adapted *from*

Novak, J. D. and Gowan, D. B. (1984). *Learning How to Learn.* New York, NY: Cambridge University Press.



THREATS TO WATER QUALITY

There are many local concerns regarding water quality in New York State and these frequently serve as the animating factors in citizen science programs. Fossil fuel extraction, agricultural and industrial/manufacturing activities, and solid waste treatment all pose potential threats to clean water. These insults to the environment are what gets citizens charged, ready to 'fight in the trenches' (or sample the stream bottoms) to protect our local water resources.

Natural Gas Extraction

Recently the specter of hydraulic fracturing processes in New York focused the attention of many environmental organizations and activists. Colloquially know as *fracking*, this method of natural gas extraction has given conventional gas drilling technologies a new 'twist' – literally. Oil and gas extraction has been performed for over a century by drilling vertical shafts into the earth to pierce fossil fuel rich reservoirs underground and convey the contents to the surface. Frack wells use a similar vertical shaft but continue the drilling in horizontal directions (typically miles below the surface) by turning/twisting the drill bit at a 90° angle (Mooney). A proprietary cocktail of water, solvents and sand is forcibly injected into the well causing the resource rich shale below to fracture and crack. This frees the natural gas, once trapped by the rock layers, which is siphoned back up the well shaft within the previously injected slurry-mix.

Throughout the hydraulic fracturing process there are numerous ways in which oil/gas recovery can harm water resources (Ridlington & Rumpler; Cusolito). At the outset, because thousands of gallons of water are required for frack injections, the rivers themselves are often tapped for this source of water (Mooney). Reduced flow in streams has impacts not just to fish and wildlife but to vegetation as well. Ingraffia et al. have documented that over time, the concrete well casings will exhibit very high failure rates, so that in perhaps as few as two decades, cracks in the shaft may allow toxic residual extraction fluid to migrate into groundwater, wells, lakes and streams. Because not all the frack fluid is evacuated from the well, years after the oil and gas industry has left a mining site, threats to water will remain (Mooney). Spills also occur, not just around the rig site but also in the transportation of oil/gas resources and the frack-extraction chemicals. In some states, produced frack water/brine is used to de-ice road surfaces in winter and can leach into groundwater or run off into streams (Harrington). Storage of exhumed natural gas also creates problems. Finger Lakes vineyards and wineries perceive a looming threat with Crestwood Equity Partners' proposed gas storage facility in salt caverns underneath Seneca Lake (Franz & Grant). Seneca is already the saltiest of the Finger Lakes and vintners worry their groves – and industry will be tainted if leaks occur at the storage facility. In 1980 mismanagement of a smaller salt cavern used by the Atlantic Richfield Company (ARCO) for propane storage in Harford Mills, NY resulted in a large fish-kill in the East Branch of the Owego Creek (NYS-DEC- Owego Creek). Residents feel justifiably wary of a repeat occurrence and groups such as *We Are Seneca Lake* and the Sierra Club *New York Water Sentinels* are working to monitor and protect our waters from the effects of natural gas production and storage.

Military & Industrial Pollution

Now in disuse, the Seneca Army Depot near Romulus, NY is a current EPA Superfund Site (USEPA). From 1941 to 2000 the 10,000-acre base was home to a military munitions distribution and storage center. Area residents concerned about pollution issues and the clean up efforts have organized to form the Seneca Lake Pure Waters Association - SLPWA. Members regularly monitor streams surrounding the depot and have periodically reported elevated levels of phosphorus (presumably from munitions residue) in the water (SLPWA). High *E. coli* bacterial counts have also been documented for Reeder Creek as certified by the Community Science Institute water laboratory of Ithaca, NY.

Industrial pollution has also negatively impacted local water sources. In 1986, volatile organic compounds (VOCs) in the form of trichloroethylene (TCE) were found in Cortlandville, NY residential wells. The pollution source was linked to prior operations at the Smith Corona (typewriter) Manufacturing Facility within the Otter Creek-Dry Creek watershed. While a settlement with Smith Corona was reached, a plume of contaminants remains in Cortland's sole source aquifer – from which the regions drinking water is supplied and monitoring of the plume's status (and migration) is ongoing (Cortland County Environmental Health; Miller et al.). As a result too, citizen scientist, Water Sentinels regularly monitor the water chemistry of Otter and Dry Creeks.

Agricultural Runoff

The Central New York and Finger Lakes area is home to a wealth of agricultural products most notably dairy products, wine, and apples. With agricultural production however comes risk of pollution. The regional rise of the 'mega' dairy farm is of some concern and in particular the common practice of liquid manure applications to farmlands. "Winter spreading" has in fact been recommended for banning by the EPA (Disa). The problem occurs when liquefied manure is sprayed on frozen (impenetrable) fields and runs off into nearby streams and lakes. Among other things, the potential then exists for eutrophication of streams (due to the increased nutrient load), elevated bacterial/ *E. coli* levels, and decreases in dissolved oxygen resulting in fish kills. In a press release, just this winter the New York State - Department of Environmental Conservation reported a manure spill north of Myers, NY. While some of the discharge migrated from Salmon Creek into Cayuga Lake, the spill was not deemed a threat to the Ithaca City municipal water supply (NYS-DEC Press Release). Even so, concerned citizens (and I) from the Community Science Institute quickly mobilized to perform benthic sampling of the affected Salmon Creek within a week of the spill report. Such efforts highlight the dedication and commitment of citizen scientists and the need for continued public environmental oversight.

CITIZEN SCIENCE ORGANIZATIONS

This section describes the activities of three representative (local to New York State) citizen science groups whose focus has been to keep a watchful eye on the afore mentioned threats to water quality: natural gas extraction, military/ industrial pollution, and agricultural runoff. For each organization I will review its history, purpose (mission), sampling metrics collected (physical, chemical, and/or biological), sampling protocols and procedures, and outcomes of group activities. The majority of this information was gleaned from the organizations' websites in addition to personal contact with organizers/members as well as attendance at workshops, symposiums, meetings, and sample outings. Table 1 is a summary of group mission statements, membership numbers, and web addresses.

Table 1.
Selected New York State Citizen Science Organizations

Sierra Club – New York Water Sentinels (SC-NYWS)

Mission Statement: "… to document the health of streams in the State of New York."
Founded: 2011
Services: Water Quality Program Training provided by ALLARM,
(Alliance for Aquatic Resource Monitoring – Dickinson College, PA)
Loans of Monitoring equipment: LaMotte Conductivity Meters
Quality Assurance/ Quality Control of Sampling
Heavy Metal analysis of Water Samples (Third Party Testing)
Volunteers: 160
Website: https://content.sierraclub.org/grassrootsnetwork/teams/ny-water-sentinels
https://nywatersentinels.org/

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NYS-DEC Water Assessment by Volunteer Evaluators (WAVE)

Mission Statement: **"…**to enable citizen scientists to collect biological data for assessment of water quality on wadeable streams in NY State."
Founded: 2012
Services: Training Sessions for Collection and Identification of Benthic Macroinvertebrates
Loans of Collection Equipment (kick nets, collection vials)
Volunteers: 160
***Website*:** http://www.dec.ny.gov/chemical/92229.html
http://www.dec.ny.gov/gmk/index.html?url=http://www.dec.ny.gov/maps/wave2016.kmz

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Community Science Institute (CSI)
[Not-for-Profit 501(c)3 tax-exempt status]

Mission Statement: "… to *foster and support environmental monitoring by volunteers in order to educate the public about natural resources and to collect scientifically credible data for use in protecting the environment and the sustainable management of natural resources."*
Founded: 2000
Services: New York State Certified Water Quality Testing Lab
Sponsor of Volunteer (Citizen Science) Stream Monitoring Programs
Synoptic (Water Chemistry/ Stream) Sampling
Red Flag Monitoring (Water Chemistry)
Biological Monitoring (Benthic Stream Sampling)
4-H2O Youth Program
Public Forums: "What's in Your Watershed?"
Staff/ Volunteers: 9/200
Website: http://www.communityscience.org/

Sierra Club – New York Water Sentinels

History

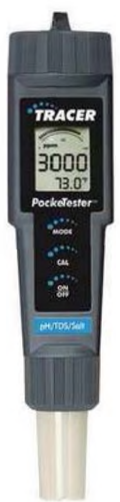
Scottish immigrant and naturalist John Muir founded the Sierra Club in 1892. From it's inception the Sierra Club has worked to "protect and restore wildlands and waterways" throughout the United States (*from* Sierra Club Strategic Plan Overarching Visionary Goals – sierraclub.org). Muir in fact lobbied for the creation of Yellowstone as the U.S.'s (and the world's) first National Park. The Club is recognized as a preeminent environmental force with membership and supporters of nearly three million who regularly lobby, march, advocate, and protest in support of pressing environmental concerns including: climate change, air/water quality, renewable energy production, endangered species, and environmental justice. An offshoot, the Sierra Club Foundation is a charitable group (IRS Code – section 501(c)(3) designation) with special emphasis on educational initiatives.

New York Water Sentinels are a subset of the Sierra Club Atlantic Chapter. Sierra Club Water Sentinels began in 2011 out of a concern (*i.e.* fear) that the oil and natural gas extraction method of hydraulic fracturing would soon be coming to the Marcellus and Utica Shale geologic formations of New York State. At that time, the southern regions of the Marcellus Shale in Pennsylvania had already been mined with increasingly deleterious effects to water quality in that state (Neuhauser; Cusolito). Pennsylvania had little or no baseline data regarding stream quality. When fracking 'accidents' occurred (oil effluent spillages into waterways, methane leaks into residential drinking water wells, livestock and wildlife mortality from exposure to fracking residue, etc.) the industry was easily able to avoid culpability since historical (*i.e.* pre-fracking) evidence of water quality was lacking. New York Water Sentinel sampling is focused primarily in the Southern Tier and counties adjacent to Pennsylvania regions where hydraulic fracturing techniques are currently used to extract natural gas reserves from Marcellus Shale deposits. Sampled counties include: Allegany, Broome, Cattaraugus, Chautauqua, Chenango, Cortland, Delaware, Steuben, and Tioga (nywatersentinels.org).

Purpose

One purpose of stream monitoring in New York has been to create a baseline of water quality metrics from which comparisons of water quality may be made in the event of a contamination or spill event. With help from academics and researchers at Dickinson College (Carlisle, PA) and the Alliance for Aquatic Resource Monitoring (ALLARM), volunteers were trained to sample streams using a hand held water chemistry meter (LaMotte PockeTester – Figure 3.) to test for electrical conductivity (EC) and total dissolved solids (TDS).

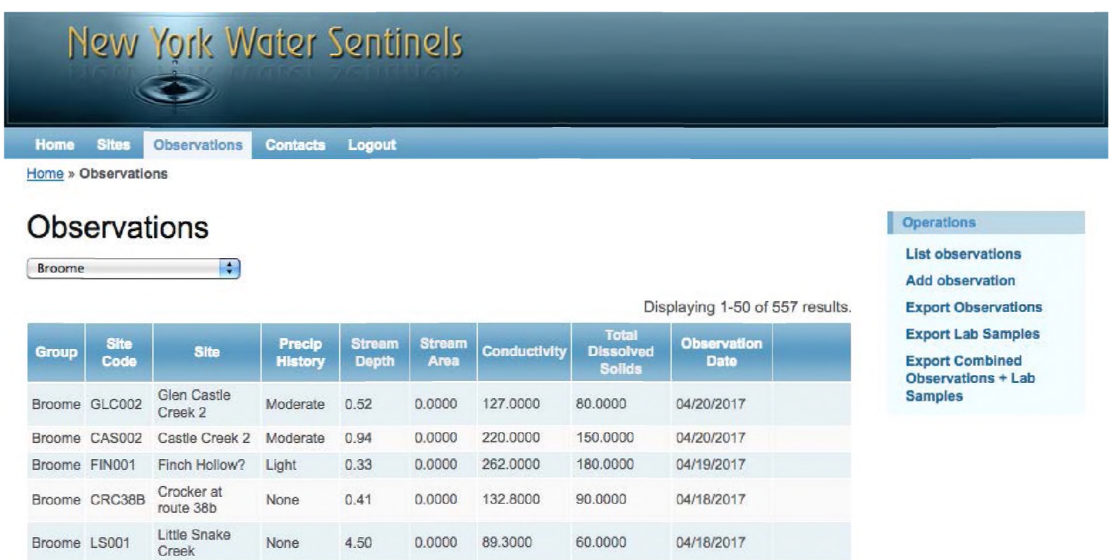
Figure 3.
Water Chemistry Apparatus – LaMotte PockeTester (LaMotte Company website)



Sampling Metrics

Conductivity is a measure of the ability of water to pass a current due to ions in the water column. The LaMotte meter is calibrated before sampling, to a standard solution of 1413 micro Siemens per centimeter (µS/cm). Total dissolved solids is a measure of the concentration in milligrams per Liter (mg/L) of various metals and salts including: Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na) as well as sulfates (SO_4), silicates (SiO_4), chlorides (Cl^-), and carbonates (CO_3) (Boyd). Additional water samples are collected as needed to evaluate water (by certified laboratory) for heavy metals such as Barium (Ba) and Strontium (Sr). Because these heavy (often radioactive) elements (Ba, Sr) do not normally occur at the earth's surface, their presence in water could be an indication of contamination from produced water (aka frack fluid) or brine. Other stream site metrics including weather conditions, precipitation, stream stage/water depth, and latitude-longitude coordinates are documented and all data are entered in a public access database/website: https://nywatersentinels.org/. Figure 4. provides sample data representing stream metrics from Broome County (April 2017).

Figure 4.
New York Water Sentinels Website – Sample Data



Group	Site Code	Site	Precip History	Stream Depth	Stream Area	Conductivity	Total Dissolved Solids	Observation Date
Broome	GLC002	Glen Castle Creek 2	Moderate	0.52	0.0000	127.0000	80.0000	04/20/2017
Broome	CAS002	Castle Creek 2	Moderate	0.94	0.0000	220.0000	150.0000	04/20/2017
Broome	FIN001	Finch Hollow?	Light	0.33	0.0000	262.0000	180.0000	04/19/2017
Broome	CRC38B	Crocker at route 38b	None	0.41	0.0000	132.8000	90.0000	04/18/2017
Broome	LS001	Little Snake Creek	None	4.50	0.0000	89.3000	60.0000	04/18/2017

Protocols

Ideally water chemistry is sampled monthly or bimonthly but weather (and volunteer time constraints) frequently precludes adherence to this schedule. Minimum requirements are that streams be tested twice a year, once each during a high and low water flow event. Stream site selection is left to the discretion of the volunteer who can freely select areas of a stream that may warrant oversight. Outflows into a stream from a wastewater treatment plant, sites near industrial facilities, public parks, fishing access areas and the like are all useful locations for sampling. Volunteers generally sample in groups or teams seeking publically accessible waterways and not private or "posted" property, unless otherwise granted permission by a landowner.

For each stream sampled, date, weather and stream depth are recorded. Water is tested on site for conductivity and total dissolved solids, either by direct insertion of the LaMotte meter into the stream, or insertion into a bottle of collected stream water. Other than the hand-held conductivity meter and a measuring gauge/stick, pencil, paper, and perhaps boots are all the equipment necessary of sampling. Data are entered online into the New York Water Sentinel website. Twice a year Quality Assurance – Quality Control tests are made. Volunteers collect stream samples in plastic bottles (provided by NY- Water Sentinels) that are tested for conductivity and TDS. These lab results are then compared to the field meter data provided by the volunteer. Conductivity calibration fluid is replenished and supplied to sentinels annually.

Outcomes

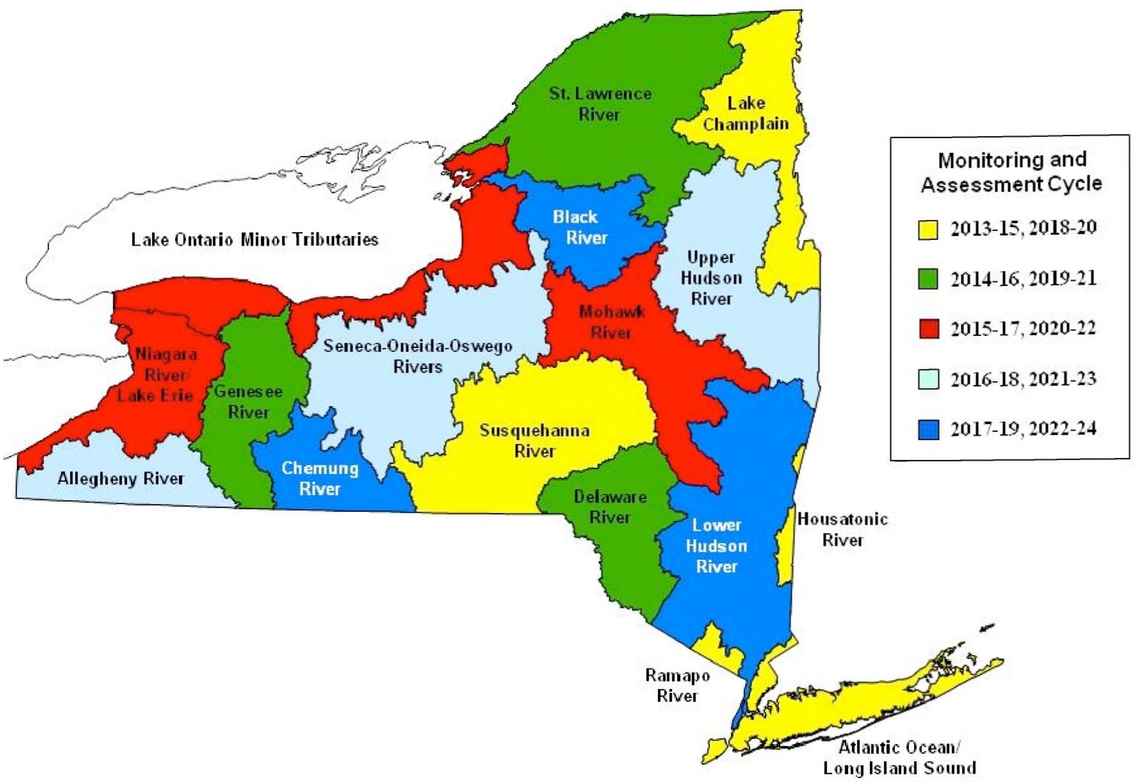
Sentinels as well as members of the public can review stream data online, free-of-charge. Although volunteers are not "credentialed" their efforts in collecting baseline water quality data are none-the-less valuable. Sentinels are encouraged to be alert to conductivity values that exceed three times the average reported value for any given stream. If conductivity spikes occur this may be an indication of a spill/contaminant in the waterway. Reports can be made to local NY-DEC, Soil & Water Conservation, and/or health department officials to investigate water chemistry using certified labs/techniques. While sentinels are not 'professionals' they are empowered as knowledgeable citizens and protectors of water quality. The Sierra Club periodically sponsors workshops for members and the public at large to educate citizens and inform them of current water issues. This year (25 March 2017) a symposium was held at Cornell University - *Water Law for Activists* - organized by the Sierra Club Atlantic Chapter and the Cornell Law School. Guest speakers included environmental lawyers, activists and riverkeepers with advice for citizens working to resolve local water challenges.

NYS Department of Environmental Conservation – Water Assessment by Volunteer Evaluators

History

The NYS-DEC was established in 1970, serves nine regions throughout the state and is staffed by approximately 3000 employees. The stated mission of the NYS-DEC is "to conserve, improve and protect New York's natural resources and environment and to prevent, abate and control water, land and air pollution, in order to enhance the health, safety and welfare of the people of the state and their overall economic and social well-being (NYS-DEC website)." New York State (NYS) Government mandates that all waterways in the state be assessed every five (5) years. The Department of Environmental Conservation (DEC) is tasked with fulfilling this directive and works to evaluate streams within 17 major watersheds/ drainage basins on a rotating basis. A map of the New York Statewide Monitoring and Assessment Schedule for these watersheds is depicted in Figure 5.

Figure 5.
New York Statewide Monitoring and Assessment Schedule
http://www.dec.ny.gov/chemical/29576.html



Purpose

In recent years, funding restraints (*i.e.* budget cutbacks) have seriously hampered DECs ability to meet its legal obligations for stream monitoring, so starting with a pilot program in 2012 the DEC instituted Water Assessments by Volunteer Evaluators (WAVE) to help document stream health. WAVE sampling focuses on the biological monitoring of *benthos*. These are the bottom dwellers of streams, mostly invertebrates – insect larvae and nymphs that live in the riverbed sediment and on, between, and under rocks. Three taxonomic Orders of insects are especially useful in assessing water quality: Ephemeroptera (Mayflies), Plecoptera (Stoneflies), and Tricoptera (Caddisflies) (EPT) (Figure 6). These insect nymphs appear to be more sensitive to pollutants/ toxins, sedimentation, eutrophication/ nutrient overload, and increased pH/ acidification. Their diversity and abundance is correlated with stream health and water purity and so their presence (or absence) in a streambed is key to water quality assessment. WAVE sampling works to flag potentially impaired streams for further/ professionally certified investigation by NYS-DEC staff.

Figure 6.
EPT – Ephemeroptera (Mayflies), Plecoptera (Stoneflies), and Tricoptera (Caddisflies)
(Photo attribution – NYS-DEC Website - Freshwater Macroinvertebrates of NY State)

Ephemeroptera – Leptohyphidae

Little Stout Crawler

Plecoptera – Perlidae

Common Stonefly

Tricoptera – Hydropsychidae

Common Netspinner

Sampling Metrics

WAVE sampling includes stream Habitat Assessment, User Perception, and Benthic Macroinvertebrate (BMI) collection and identification. Sample site habitat is observed and evaluated for riparian vegetation zone width, stream bank stability/ erosion, sedimentation, quality of streambed substrate (gravel, cobbles, boulders), channel flow (including water velocity and depth), presence/ extent of riffles (rapid flow, oxygenated areas of the stream) and evidence of channelization or other human alterations. User perception is graded according to a subjective determination of one's ability (or desire) to swim, fish, or boat in the waterway. Observations are made regarding water clarity, presence of phytoplankton and periphyton (algae suspended in the water column or on the rocks/substrate), aquatic plants, odor, trash, and the presence of discharge pipes or culverts.

The DEC has ranked benthic organisms according to their 'tolerance' of environmental stressors and has designated certain ones as either "most" or "least" desirable (Table 2). Streams are evaluated as to how many of the "most desirable" insect Families are found in a sample. The presence of six or more (≥6) 'desirable' Families in a sample indicate that a stream is likely *not* adversely impacted by pollution, sedimentation, or other environmental 'stressors'. Alternatively a stream sample with greater than four (>4) "least desirable" benthos is flagged as an indicator of a potentially impaired stream. Samples with both six or more 'desirables' and four or more 'undesirables' indicate non-impairment, since quality streams exhibit a wealth of diverse benthos (good, bad, and ugly).

Table 2.
NYS-DEC (WAVE) Website
Most & Least Wanted Insect (Taxonomic) Families – and Other Invertebrate Groups

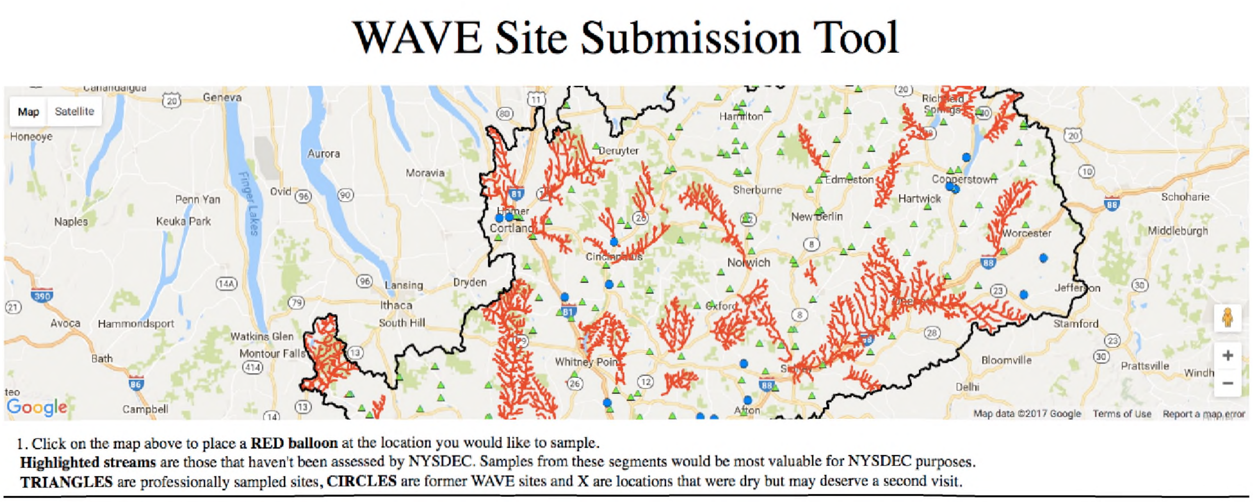
Insect ORDER	**Insect FAMILY**	
	LEAST Wanted	**MOST Wanted**
Coleoptera (Beetle)	Haliplidae	Psephenidae
Diptera (Fly)	Chironomidae, Simuliidae, Tabanidae	Athericidae
Ephemeroptera (Mayfly)		Baetiscidae, Caenidae, Ephemerellidae, Ephemeridae, Heptageniidae, Isonychiidae, Leptohyphidae, Leptophlebiidae Polymitarcyidae, Potamanthidae
Hemiptera (True Bugs)	Corixidae	
Megaloptera (Alder/Dobsonfly)	Sialidae	Corydalidae
Odonata (Dragon/Damselfly)	Calopterygidae, Coenagrionidae, Cordulegastridae	Gomphidae
Plecoptera (Stonefly)		Capniidae, Chloroperlidae, Leuctridae, Nemouridae, Peltoperlidae, Perlidae Perlodidae, Pteronarcidae
Trichoptera (Caddisfly)		Brachycentridae, Glossosomatidae, Helicopsychidae, Hydroptilidae, Lepidostomatidae, Odontoceridae, Philopotamidae, Polycentropodidae, Rhyacophilidae, Uenoidae
Invertebrate Sub/PHYLUM	**LEAST Wanted**	**MOST Wanted**
Crustacea (Scuds, Isopods)	Amphipoda, Asellidae	
Mollusca (Snails, Bivalves)	Lymnaeidae, Pelecypoda, Physidae	
Annelida (Worms, Flatworms)	Hirudinea, Turbellaria	

Protocols

WAVE sampling is conducted annually from July 1st through September 30th. Each spring, prior to the sampling season, the Department of Environmental Conservation holds daylong WAVE training workshops at various locations throughout New York. Volunteers learn sampling protocols from hands-on field and lab/classroom instruction. Equipment such as kick nets, sample vials and data submission forms are provided to volunteers.

The DEC maintains an online survey tool to document which streams have been evaluated and which still need assessment. Figure 7. represents an example of steams yet to be analyzed within the Upper Susquehanna River Basin; these are highlighted (in red) on a state map of waterways: (http://www.hrecos.org/WAVE.Data/WAVE.html) Using this tool volunteers select streams and submit proposed sample site locations (and sampling dates) to the DEC WAVE Coordinator, who may accept, reject, or propose alternate site selections. Once sites are approved, volunteers may proceed with sampling.

Figure 7.
WAVE Site Selection Tool/ Map (NY-DEC Website)

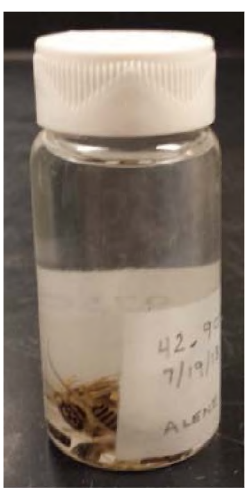


Upon arrival at the sample site the citizen scientists note the date, time and current weather conditions. They then make assessments regarding habitat and perceived suitability for wading/swimming, boating, or recreating in the water. These are recorded on the WAVE Habitat Assessment and User Perception forms provided by the DEC. Next a kick sample of the benthos is collected. This is done by selecting a stretch of stream with "riffles." These are relatively shallow places where water visibly 'bubbles' over the rocks. It is this bubbling or ripple effect that allows air (oxygen) to mix with water. Benthic organisms thrive in well-oxygenated waters and will seek out riffles for their homes so the best place to sample for BMI is where they live – in the riffles.

BMI are caught with a kicknet placed immediately downstream of a 'scuffled' river-bottom riffle (Figure 8). Kicking the streambed substrate dislodges the benthos from their homes. They flow with the current into the net to be scooped up and collected into a bucket. WAVE protocol calls for five (linear – though not necessarily contiguous) meters of streambed sampling in five (5) minutes of kicking into the collection net. In reality, this five minutes of kicknet sampling is closer to half an hour or so, since transferring the sample into the collection bucket and the net's placement in the riffle are not included in the timing. Once the collection is in the bag (*i.e.* net/bucket), organisms are plucked from the sample to be identified 'live' under a dissecting scope. Where possible benthos are keyed to taxonomic Family level. While this identification is not mandatory, it is required that at least one representative specimen for each unique benthic Family be included in a voucher collection for submission to the DEC. Selected organisms are preserved in a small vial filled with 90% alcohol (Figure 9.) and sent to the DEC with the accompanying stream sample documentation. The remainder of the benthic horde is repatriated back to the stream from whence they came.

Figure 8.
WAVE Kicknet Sampling
(NYS-DEC Website – Instructions for Collecting & Submitting WAVE Samples)

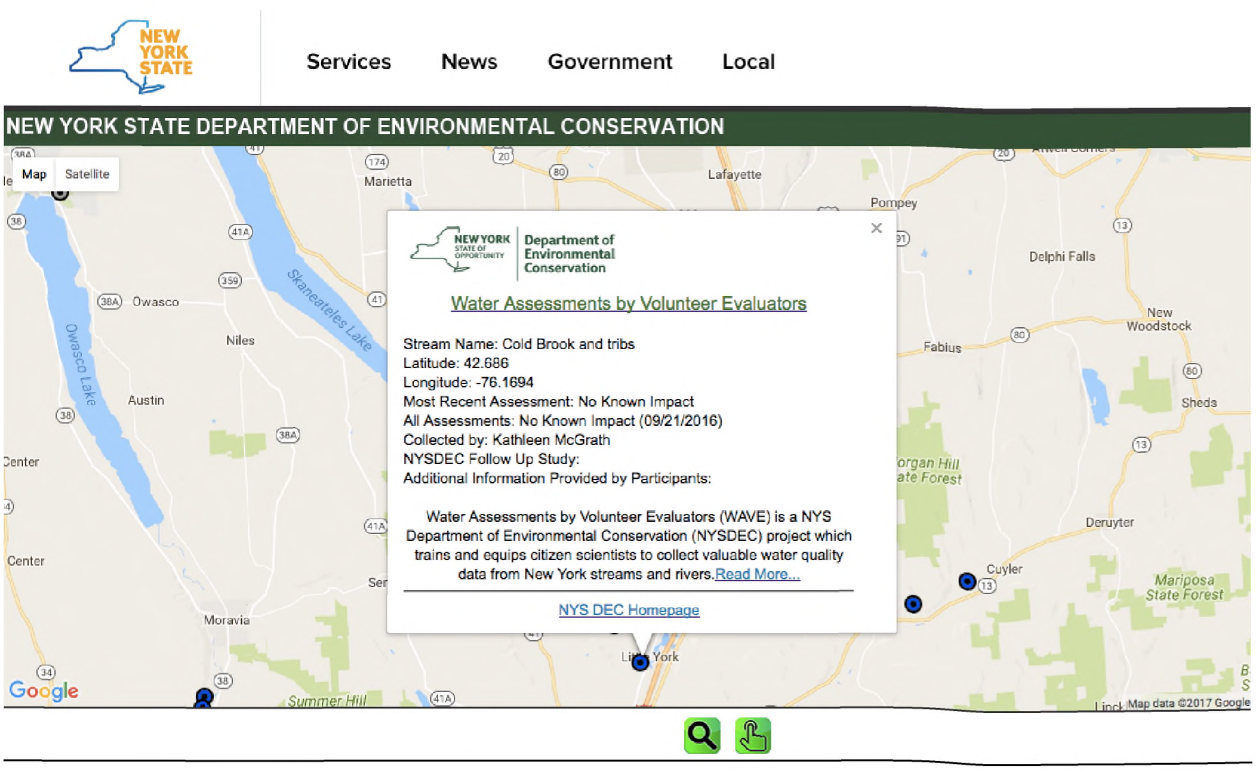
Figure 9.
WAVE Sample Voucher Vial (NYS-DEC Website)



Outcomes

Upon receipt of the stream sample voucher, the DEC-WAVE Coordinator checks the benthic collection for identification accuracy and Quality Assurance/Control. Depending on the organisms represented in the sample, streams are designated as *unimpaired* or *possibly impaired*. Results are sent (via email) to WAVE volunteers and posted on the DEC website for public access (Figure 10.). Streams assessed as (possibly) *impaired* are subject to further scrutiny (*i.e.* sampling) by professional DEC biologists. The WAVE sampling is important because it helps allocate limited DEC staff time and resources for surveying of the most environmentally vulnerable waterways.

Figure 10.
WAVE Map and Stream Assessment Designation (NYS-DEC Website)



This year, in addition to online resources and evaluation results, the DEC organized a workshop for volunteers, held at Peebles Island State Park (Waterford, NY), Thursday, April 6, 2017. Entitled *From Data to Action,* the daylong program featured panel discussions and presentations by DEC staff, WAVE volunteers, private sector researchers and university academics. Participants viewed water-sampling analyses of WAVE and other data and were offered suggestions on how to affect local changes in water policy.

Community Science Institute (CSI)

History

CSI is a nonprofit organization that includes combined educational outreach programing with a certified (pay-for-fee) water laboratory. It was founded by biochemist Steve Penningroth in 2000 and is located at the Cornell University Langmuir Laboratory facility in Ithaca, NY. The paid staff of nine personnel and volunteer corps of approximately 200 work to monitor and educate the local citizenry regarding water resource issues.

Purpose

The stated mission of CSI "is to empower citizens to monitor and protect local water resources for sustainable management" (CSI Website). Toward that end the organization has developed three citizen science programs: Synoptic Sampling, Red Flag Monitoring and Biological Monitoring. Synoptic Sampling provides a 'snapshot' evaluation of stream water chemistry taken twice a year. Red Flag groups collect water chemistry data on a monthly or bimonthly basis. The Biological group specializes in benthic macroinvertebrate collection and identification as a measure of stream water quality.

Sampling Metrics

The Synoptic and Red Flag programs collect similar water chemistry data. Like the Sierra Club Water Sentinels, volunteers in these groups take measurements of electrical conductivity and total dissolved solids (TDS) for stream water. In addition to these, data is also collected for water hardness, dissolved oxygen, pH, and water temperature (Table 3).

Table 3.
CSI- Synoptic & Red Flag Water Chemistry Metrics (CSI Website)

WATER CHEMISTRY METRICS
WATER TEMPERATURE (T) – in degrees Celsius
pH – a measure of the concentration of Hydrogen (H+) and Hydroxide (OH-) ions
DISSOLVED OXYGEN (DO) – Oxygen dissolved in water (mg/L)
WATER HARDNESS - measures dissolved metals, especially Calcium (Ca), Magnesium (Mg)
CONDUCTIVITY – a measure of water's ability to 'conduct' electricity, or pass a current. The units of measurement are *μS/cm (micro Siemens per centimeter).* This metric is related to the concentration of ions (charged particles) in the form of salts in the water column.
TOTAL DISSOLVED SOLIDS (TDS) – a measure of the concentration (ppm) of inorganic salts in the water, including: Calcium (Ca^+), Magnesium (Mg^+), Potassium (K^+), Sodium (Na^+), Bicarbonates (HCO_3^-), Chlorides (Cl^-), and Sulfates (SO_4^-)

Biological monitoring metrics involve the categorization (with regard to both abundance and tolerance) of identified benthic macroinvertebrates (BMI). The presence of Mayflies/ Ephemeroptera, Stoneflies/Plecoptera, and Caddisflies/Tricoptera (EPT) in the streambed is an especially good indicator of water quality since these organisms are ultra-sensitive to pollutants/impurities. Table 4 is a list of taxonomic Families of EPT and their associated tolerance to stream 'stressors' as recognized by the NYS-DEC. The tolerance scale is from zero to ten (0-10) where zero indicates an organism that is highly *intolerant* of pollution, and ten represents benthos highly tolerant to water pollutants and other stressors (NY-DEC- Div Water).

Table 4.
Tolerance Values of EPT Benthic Macroinvertebrates (NYS-DEC Division of Water)

ORDER/ Family	**Tolerance**
EPHEMEROPTERA (Mayflies)	
Baetidae (Small Minnow)	**6**
Baetiscidae (Armored)	**4**
Caenidae (Small Squaregill)	**6**
Ephemerellidae (Spiny Crawler)	**2**
Ephemeridae (Common Burrowing)	**2**
Heptageniidae (Flat Head)	**3**
Isonychiidae (Brushlegged)	**2**
Leptohyphidae (Little Stout Crawler)	**4**
Leptophlebiidae (Prong-gilled)	**4**
Polymitarcyidae (Pale Burrowing)	**2**
Potamanthidae (Hackelgill)	**4**
PLECOPTERA (Stoneflies)	
Capniidae (Small Winter)	**3**
Chloroperlidae (Green)	**0**
Leuctridae (Rolled-winged)	**0**
Nemouridae (Spring)	**2**
Peltoperlidae (Roachlike)	**0**
Perlidae (Common)	**3**
Perlodidae (Patterned)	**2**
Pteronarcyidae (Giant)	**0**
Taeniopterygidae (Winter)	**2**
TRICHOPTERA (Caddisflies)	
Brachycentridae (Humpless Case-maker)	**2**
Glossosomatidae (Saddle Case-maker)	**1**
Helicopsychidae (Snail-case)	**3**
Hydropsychidae (Common Netspinner)	**5**
Hydroptilidae (Micro)	**6**
Lepidostomatidae (Lepid. Case-maker)	**1**
Leptoceridae (Long-horned)	**4**
Limnephilidae (Northern Casemaker)	**4**
Odontoceridae (Strong Case-maker)	**0**
Philopotamidae (Finger Net)	**4**
Polycentropodidae (Tube Maker)	**6**
Psychomyiidae (Net Tube)	**2**
Rhyacophilidae (Free Living)	**1**
Uenoidae (Unoid Case-maker)	**3**

Several metrics for BMI are tabulated. These include scores for *total family richness, family biotic index, EPT richness, percent model affinity, and biological assessment profile (BAP).* An explanation of each with corresponding scoring is given in Table 5.

Table 5.
CSI – Biological Monitoring Metrics & Scoring (CSI Website)

METRICS	IMPACT VALUES			
	Non/None	Slight	Moderate	Severe
Total Family Richness: *the number of unique aquatic insect families found in a sample.*	>13	10-13	7-9	<7
Family Biotic Index: *a weighted average of the sampled insect families tolerance to pollution.*	0-4.5	4.51-5.50	5.51-7.00	7.01-10.00
EPT Richness: *total BMI count of insect families within the Orders of* ***E****phemeroptera,* ***P****lecoptera, &* ***T****ricoptera.*	>7	3-7	1-2	0
Percent Model Affinity: *comparative score/percentage based on NYS-DEC optimal abundance of 7 major BMI groups within the sample.*	>64%	50-64%	35-49%	<35%
Biological Assessment Profile (BAP): *combined score of the preceding four metrics, converted for a 0-10 rating.*	7.5-10.0	5.0-7.5	2.5-5.0	0-2.5

Though the collection and identification of benthic macroinvertebrates is the most important aspect of biological monitoring, at the time of sampling other physical attributes of the stream site are noted/recorded. These include: stream width, water temperature, depth and velocity, turbidity, vegetative growth in and around the stream, riffle size, and streambed substrate composition.

Protocols

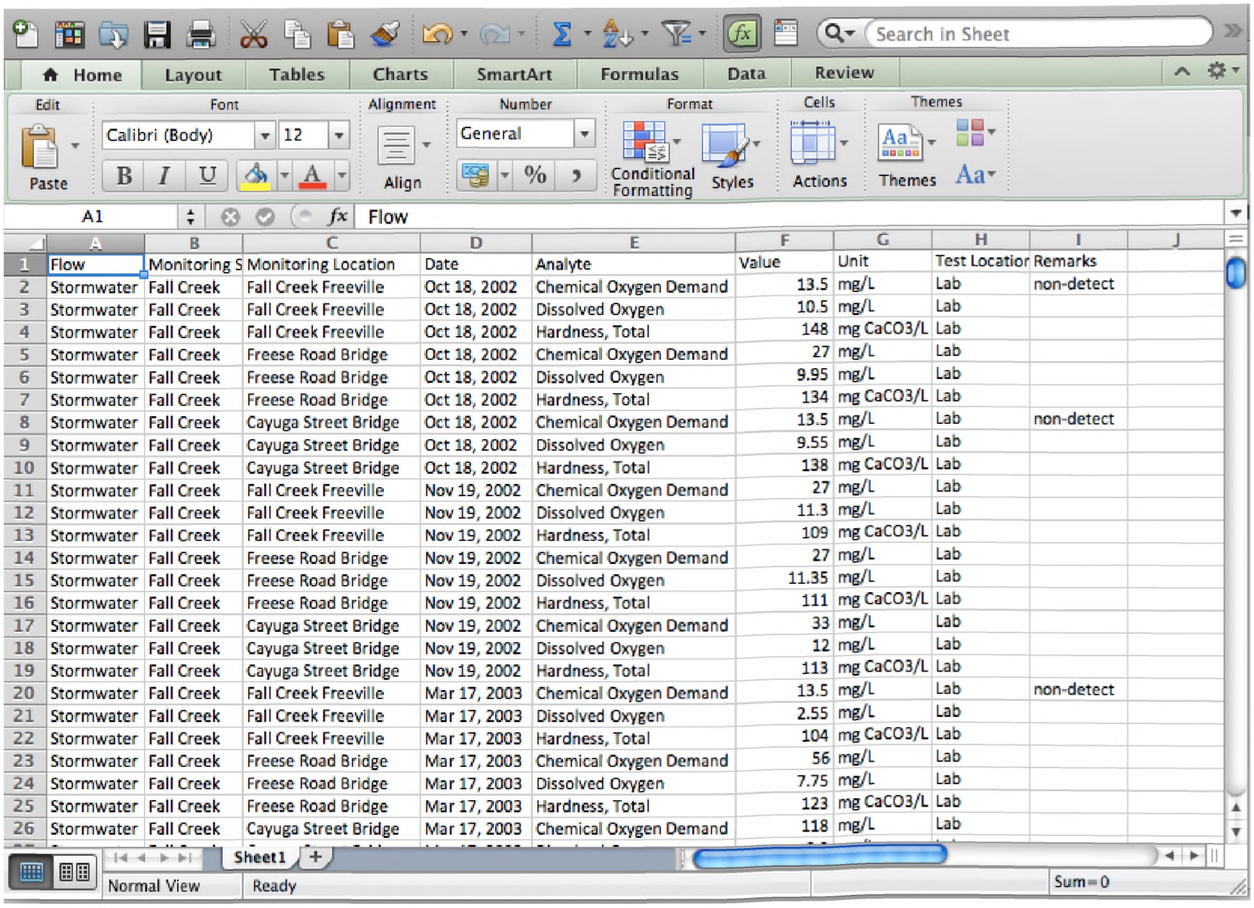
CSI sampling protocols are a modification of the Hudson Basin River Watch standard operating procedures. Sampling can be done at anytime of the year that it is safe to do so, but most often collections are made in the spring, summer and fall. Sites are usually identified on Google Maps/Earth and latitude/longitude coordinates are determined prior to a streamside visit. The first order of business once at a biological monitoring location is to choose an optimal BMI sampling site, generally a stretch of river with ample riffles at least 5 meters long/wide. Next, habitat assessments are made of a 200-foot section of the waterway including areas upstream and below the BMI selected collection area. Kicknet collection procedures are identical to those done for NYS-DEC WAVE samples, with the exception that all organisms collected are preserved in 90% alcohol to be sorted and identified back at the CSI laboratory.

Back at the lab, the collection is first rinsed in water to clear the sample of mud, extraneous debris and volatile alcohol fumes. Each sample is then evenly distributed in shallow, 18" x 24" tray of water – gridded/demarcated off into 6" squares, labeled one (1) through twelve (12). Up to three of these squares are randomly selected from which to analyze subsamples for BMI. A minimum of 200 BMI organisms are plucked, identified, and counted from the combined subsamples. Citizen scientist volunteers use standard taxonomic keys, picture identification guides and the advice and consent of the certified BMI lab director to analyze the sample. Where identification is questionable, the director determines an organism's identity to ensure quality control. Wherever possible the invertebrates are keyed to at least taxonomic Family and numbers are recorded on a data sheet. All subsamples are again preserved in 90% alcohol and stored at the CSI Lab in case of future need for review or reassessment.

Outcomes

Synoptic and Red Flag data are downloadable, free from the CSI Website. They may be 'filtered' according to stream site, watershed, sample date, and water chemistry metric. A sample of the Red Flag data from Fall Creek – exported to an EXCEL worksheet is seen in Figure 11.

Figure 11.
CSI – Red Flag (subset) Results for Fall Creek Water Chemistry. (CSI Website)



	A	B	C	D	E	F	G	H	I
1	Flow	Monitoring S	Monitoring Location	Date	Analyte	Value	Unit	Test Locatior	Remarks
2	Stormwater	Fall Creek	Fall Creek Freeville	Oct 18, 2002	Chemical Oxygen Demand	13.5	mg/L	Lab	non-detect
3	Stormwater	Fall Creek	Fall Creek Freeville	Oct 18, 2002	Dissolved Oxygen	10.5	mg/L	Lab	
4	Stormwater	Fall Creek	Fall Creek Freeville	Oct 18, 2002	Hardness, Total	148	mg CaCO3/L	Lab	
5	Stormwater	Fall Creek	Freese Road Bridge	Oct 18, 2002	Chemical Oxygen Demand	27	mg/L	Lab	
6	Stormwater	Fall Creek	Freese Road Bridge	Oct 18, 2002	Dissolved Oxygen	9.95	mg/L	Lab	
7	Stormwater	Fall Creek	Freese Road Bridge	Oct 18, 2002	Hardness, Total	134	mg CaCO3/L	Lab	
8	Stormwater	Fall Creek	Cayuga Street Bridge	Oct 18, 2002	Chemical Oxygen Demand	13.5	mg/L	Lab	non-detect
9	Stormwater	Fall Creek	Cayuga Street Bridge	Oct 18, 2002	Dissolved Oxygen	9.55	mg/L	Lab	
10	Stormwater	Fall Creek	Cayuga Street Bridge	Oct 18, 2002	Hardness, Total	138	mg CaCO3/L	Lab	
11	Stormwater	Fall Creek	Fall Creek Freeville	Nov 19, 2002	Chemical Oxygen Demand	27	mg/L	Lab	
12	Stormwater	Fall Creek	Fall Creek Freeville	Nov 19, 2002	Dissolved Oxygen	11.3	mg/L	Lab	
13	Stormwater	Fall Creek	Fall Creek Freeville	Nov 19, 2002	Hardness, Total	109	mg CaCO3/L	Lab	
14	Stormwater	Fall Creek	Freese Road Bridge	Nov 19, 2002	Chemical Oxygen Demand	27	mg/L	Lab	
15	Stormwater	Fall Creek	Freese Road Bridge	Nov 19, 2002	Dissolved Oxygen	11.35	mg/L	Lab	
16	Stormwater	Fall Creek	Freese Road Bridge	Nov 19, 2002	Hardness, Total	111	mg CaCO3/L	Lab	
17	Stormwater	Fall Creek	Cayuga Street Bridge	Nov 19, 2002	Chemical Oxygen Demand	33	mg/L	Lab	
18	Stormwater	Fall Creek	Cayuga Street Bridge	Nov 19, 2002	Dissolved Oxygen	12	mg/L	Lab	
19	Stormwater	Fall Creek	Cayuga Street Bridge	Nov 19, 2002	Hardness, Total	113	mg CaCO3/L	Lab	
20	Stormwater	Fall Creek	Fall Creek Freeville	Mar 17, 2003	Chemical Oxygen Demand	13.5	mg/L	Lab	non-detect
21	Stormwater	Fall Creek	Fall Creek Freeville	Mar 17, 2003	Dissolved Oxygen	2.55	mg/L	Lab	
22	Stormwater	Fall Creek	Fall Creek Freeville	Mar 17, 2003	Hardness, Total	104	mg CaCO3/L	Lab	
23	Stormwater	Fall Creek	Freese Road Bridge	Mar 17, 2003	Chemical Oxygen Demand	56	mg/L	Lab	
24	Stormwater	Fall Creek	Freese Road Bridge	Mar 17, 2003	Dissolved Oxygen	7.75	mg/L	Lab	
25	Stormwater	Fall Creek	Freese Road Bridge	Mar 17, 2003	Hardness, Total	123	mg CaCO3/L	Lab	
26	Stormwater	Fall Creek	Cayuga Street Bridge	Mar 17, 2003	Chemical Oxygen Demand	118	mg/L	Lab	

From the numbers and types of BMI recorded, the various metrics previously described are calculated. Sample BMI results for 2016 are given in Figure 12. These are available for viewing and/or download on the CSI Website – free of charge.

Figure 12.
CSI – Biomonitoring Results 2016 (CSI Website)

non-impacted
slightly impacted
moderately impacted
severely impacted

THE COMMUNITY SCIENCE INSTITUTE
Bio-monitoring RESULTS 2016

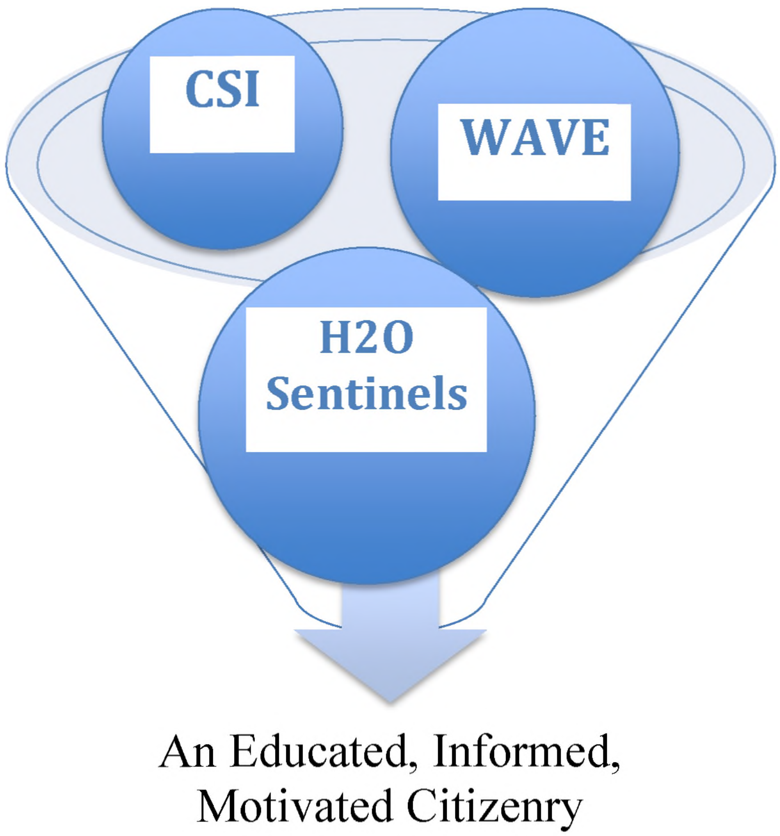
Cayuga Lake Watershed	Total Family Richness	EPT Richness	Family Biotic Index	Percent Model Affinity	Density Orgs/sample	BAP Value Biological Assessment Profile
Enfield Creek - Mouth **5/27/16** 42.398095N, 76.546700W just upstrm of rte 13 bridge	**18.0** no impact	**11.0** no impact	**4.77** slight impact	**74%** no impact	450*	**8.8** no impact
Six Mile Creek-Slatvl600rd **9/3/16** 42.396300N, 76.334333W Slaterville 600 Rd.	**15.5** no impact	**8.0** no impact	**3.48** no impact	**65%** no impact	1,856	**8.6** no impact
Six Mile Creek-upstm GerCrs **9/1/16** 42.402909N, 76.436369W German Cross Rd	**19.5** no impact	**10.0** no impact	**4.54** slight impact	**58%** slight impact	not calculated (analyzed live)	**8.3** no impact
Six Mile Creek-blw Potters Falls **9/2/16** 42.419465N, 76.465312W first good riffle dwnstrm of Potters Falls	**11.5** slight impact	**5.0** slight impact	**4.34** no impact	**51%** slight impact	1,548 (analyzed live)	**6.5** slight impact
Six Mile Creek-Plain Street **8/28/16** 42.434082N, 76.504191W just downstream of Plain St. Bridge	**11.5** slight impact	**6.5** slight impact	**4.43** no impact	**51%** slight impact	646 (analyzed live)	**6.5** slight impact
Fall Creek **8/31/ 6** 42.457884N, 76.437961W Freese Rd	**12.0** slight impact	**8.0** no impact	**5.09** slight impact	**60%** slight impact	3933	**6.9** slight impact

In addition to the sampling data and water quality information provided on the CSI website, the organization sponsors periodic free lectures to update the public regarding *"What's in Your Watershed."* CSI also holds Laboratory 'open house' nights and an annual symposium for volunteers and the public at large. This year's symposium was on Saturday, April 8, 2017 at the Tompkins County Library in downtown Ithaca, NY. Data/results from the most recent sampling year (2016) was presented by founder Steve Penningroth, and other representatives from the three CSI citizen science monitoring groups. The keynote speaker, Mark Witmer is the current Town of Caroline Board Supervisor and a CSI Red Flag volunteer monitor. He related his sampling experiences and confided that it was his work with CSI that spurred him to seek public office as a means to protect community waters.

SUMMARY & RECOMMENDATIONS FOR BRIDGING THE GAP

Citizen Science initiatives are valuable societal resources that seek to both educate and energize the public. The epistemological paths of 'learning how to learn' and 'knowing what we know' follow the contours of the virtual streambed of aquatic science/ water monitoring. Passing from citizen inquiry and environmental concerns, to action through scientific observation, data collection and analysis, to policy awareness and political/governmental engagement. It is when the public is spurred to literally 'get their feet wet' that real progress is made in protecting our water resources. Water Sentinels have served as watchdogs over local streams to ensure that if and when industrial pollutants enter a waterway, we will know about it. Their additional efforts at marching, lobbying, and petitioning the government contributed to Governor Cuomo's ultimate ban on hydraulic fracturing in New York State. WAVE volunteer efforts have helped ease the fiscal constraints of State agencies charged with surveying wetlands and their data collection tallies have alerted DEC officials to the need for further monitoring of the most vulnerable streams. WAVE submissions help inform future natural resource management directives for State water resources. Lastly, local non-profits such as the Community Science Institute build community awareness of local water issues that need to be addressed. In all three organizations cited, the data generated (as with the water resources) is freely flowing and accessible to the public. It is through the filter of citizen science that the public's efforts are shaped and channeled into an educated, informed, and motivated citizenry (Figure 13.)

Figure 13.
Citizen Science Water Filter



Bridging the gap between people and policy is being accomplished through citizen science initiatives. An interesting, recurring recommendation given to participants at each of the recent symposia/workshops offered by the Sierra Club, NYS-DEC, and CSI was the need for citizens to become *politically* engaged to better protect/steward resources. Citizen Science at its best works not only to enhance our knowledge of science but also to solidify our investment in *citizenship* (Lewenstein). Lawyer-presenters at the *Water Law for Activists* Symposium stated that 'litigation' should not be relied upon as a remedy for water issues. Legal resolutions take years to work through the court system and solutions/reparations are often inadequate. Far better to seek an elected office or appointed position (mayor, town supervisor, planning commissioner, water board member, etc.) to effect change directly and in a timely manner. WAVE Workshop presenters suggested that *county* funds could/should be designated for water protection programs (through local voter promotion) rather than relying on state funding sources. And of course there is the example of Mark Witmer, CSI volunteer-turned-town-supervisor in the service of clean water protection. Politics for the citizen scientist may indeed be an important next step.

In addition to the pursuit of politics by the citizen scientist, I see an imperative for our politicians to 'get down and dirty' with citizen scientists. Just as the public can benefit by getting their feet wet to sample a stream, public officials might better appreciate the environmental concerns of their constituents if viewed from the level of a streambed. Perhaps instead of an organized 'town hall' meeting, elected officials could be invited to a stream sampling event. If politicians' schedules preclude collecting benthic samples, maybe a staffer could be sent to a stream sampling as a surrogate. In any event bridging the divide between people and policy will continue to be an important strategy to remedying our shared environmental challenges.

Works Cited (annotated)

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Creative Commons training manual for citizen science monitoring of streams under potential threat of pollution/ impact from oil and natural gas extraction. Sampling protocols developed by ALLARM/ Dickinson College, Carlisle, PA.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J. & Wilderman, C. C. (2009). Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. *A CAISE Inquiry Group Report*. Washington, D.C.: Center for Advancement of Informal Science Education (CAISE).

This report assesses ten projects funded in part by the National Science Foundation. All included varying degrees of citizen participation in the design, data collection, analysis, interpretation and dissemination of scientific investigations. Projects were classified into three categories determined by the degree of public contribution: contributory, collaborative, and co-created. The authors assess the quality of outcomes in relation to the extent of citizen engagement in the projects.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V. & Shirk, J. (2009). Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *Bioscience,* 59(11): 977-984. doi: 10.1525/bio.2009.59.11.9

A review of citizen science as employed by the Cornell Laboratory of Ornithology (CLO). Projects include BirdSleuth, eBird, FeederWatch, Great Backyard Bird Count, and NestWatch among others. Raw data has been used for research and publication in peer-reviewed journals and much is available free, online (www.avianknowledge.net). The authors present their model for organizing research driven by citizen science data collection.

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J. & Parrish, J. K. (2014). Next Steps for Citizen Science. *Science,* 343: 1436-1437. doi: 10.1126/science.1251554

Authors propose several recommendations to help further utilize and legitimate citizen science research projects. These include: rigorous volunteer training to ensure quality data collection, user-friendly analysis techniques, readily accessible (online) data/results, collaboration between citizen science groups, academics, and government agencies, volunteer preparedness for mobilization in the event of unexpected incidents (e.g. severe weather, discharges, spills, etc.).

Bonney, R., Phillips, T. B., Ballard, H. L. & Enck, J. W. (2015). Can citizen science enhance public understanding of science? *Public Understanding of Science (PUS),* 1-15. doi: 10.1177/0963662515607406

Authors investigate the potential educational value of citizen science. They find modest though potentially important increases in scientific literacy and understanding through public research endeavors.

Boyd, C. E. (2015). *Water Quality: An Introduction, 2nd ed.* New York: Springer International.

Basic text on hydrology and the physical, chemical and biological attributes of water.

Cavalier, D. & Kennedy, E. B. (Eds.). (2016). *The Rightful Place of Science: Citizen Science.* Tempe, AZ: Consortium for Science, Policy & Outcomes.

This is a compilation of selected essays elucidating the recent history, purpose and scope of citizen science in the United States. Included are discussions of the investigative, activist and collaborative aspects of citizen science.

Cohen, I. B. (1995). *Science and the Founding Fathers: Science in the Political Thought of Thomas Jefferson, Benjamin Franklin, John Adams & James Madison.* New York, NY: W. W. Norton & Company.

Cohen highlights the importance of scientific inquiry and reason to our Founding Fathers. He suggests their educational training in math and science greatly influenced their political philosophies. The scientific interests and endeavors of Jefferson, Franklin, Adams and Madison are documented chapter by chapter.

Community Science Institute. (2017). http://www.communityscience.org/

Ithaca, NY based certified water laboratory. CSI also specializes in community outreach and education projects for all ages.

Cooper, C. B. & Lewenstein, B. V. (2016). Two Meanings of Citizen Science *in* D. Cavailier & E. B. Kennedy (Eds.), *The Rightful Place of Science: Citizen Science* (pp. 51-62). Tempe, AZ: Consortium for Science, Policy & Outcomes. ISBN-13: 978-0692694831.

The authors explore the meaning of 'citizen science' as both a democratizing and contributory public endeavor. They cite the collaborative efforts with scientists from the HIV/AIDS activist community of the 1980's and birding-hobbyists participation in the online project eBird of the 2000's.

Cortland County Environmental Health. (circa 2007). http://www.cortland-co.org/DocumentCenter/Home/View/1740

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https://www.thenation.com/article/next-drilling-disaster/

An assessment of oil and gas extraction accidents, incidents and malfeasance regarding tainted water in Dimock, PA and the consequences there of the Halliburton Loophole.

Disa, A. (18 April 2017). Mega-Dairies Mean Mega Waste for New York Communities. *EarthJustice Blog.* http://earthjustice.org/blog/2017-april/mega-dairies-mean-mega-waste-for-new-york-communities

This article on EarthJustice's Blog highlights the environmental hazards of New York State's industrial-sized dairy farms. The combined manure generated from these mega-operations generates double the sewage output from more than 60 cities in the State – including NYC.

Franz, J. & Grant, J. (11 October 2016). The War Over Wine, Water and Fuel in New York's Finger Lakes. *Public Radio International – Living On Earth.* https://www.pri.org/stories/2016-10-11/war-over-wine-water-and-fuel-new-york-s-finger-lakes

Radio report on the fears of Finger Lakes winery owners over the threat posed by the storage of natural gas produced from hydraulic fracturing. Crestwood Equity partners has proposed the storage of liquid petroleum gases (LPG) in salt caverns beneath Seneca Lake. This poses risks of both methane leaks and increased salinization of the lake.

Haklay, M. (2015). Citizen Science and Policy: A European Perspective. *The Woodrow Wilson Center, Case Study Series* (4). Washington, DC: Commons Lab, Science and Technology Innovation Program.

This report surveys the extent and successes of citizen science within the European community. Special focus is placed on the importance of factors such as geography (local, regional, state, national, and international) collaborations, policy implementation, and extent of citizen/public engagement. The author emphasizes the need for long-term financial and political commitment to citizen science initiatives.

Hamblin, J. (7 October 2014). Buy Experiences, Not Things. *The Atlantic.* https://www.theatlantic.com/business/archive/2014/10/buy-experiences/381132/

Recent research indicates that experiences hold more lasting, happy memories than does the receipt of a physical gift/thing. The author recommends the giving of 'experiential gifts.

Harrington, R. (5 March 2015). Road De-Icing Fluids May Contain Unhealthy Chemicals. *Scientific American.* https://www.scientificamerican.com/article/road-de-icing-fluids-may-contain-unhealthy-chemicals/

Brine waste from hydraulic fracturing is sometimes spread on roads in lieu of salt to prevent icing in winter. This effluent has been found to contain elevated levels of sodium, calcium, radioactive radium and strontium.

Hochachka, W. M., Fink, D., Hutchinson, R. A., Sheldon, D., Wong, W. K. & Kelling, S. (2012). Data-intensive science applied to broad-scale citizen science. *Trends in Ecology and Evolution,* 27(2): 130-137. doi: 10.1016/j.tree.2011.11.006

Hochachka et al. investigate the adequacy of citizen science protocols to 1) manage big data sets, 2) maintain participant motivation, 3) establish quality control/ quality assurance protocols, and 4) utilize novel methods of statistical analysis.

Ingraffea, A. R., Wells, M. T., Santoro, R. L. & Shonkoff, S. B. C. (29 July 2014). Assessment and Risk Analysis of Casing and Cement Impairment in Oil and Gas Wells in Pennsylvania, 2000-2012. *Proceeding of the National Academy of Sciences of the United States of America,* 111(30): 10955-10960. http://www.pnas.org/content/111/30/10955.full

Scholarly journal article documenting the failure rates of oil/gas well casings and cement linings. Well casing failures typically result in methane out-gassing to air and water sources. Fracked wells pose nearly three times the risk of gas-leak contamination as do conventional gas drilling wells.

Irwin, A. (1995). *Citizen Science: A Study of People, Expertise and Sustainable Development.* New York, NY: Routledge.

An early monograph (the first) relating the scope of citizen science and the benefits to individuals, society and science.

LaMotte Company. (2017). Web address: http://www.lamotte.com/en/

Commercial website for sale of water chemistry meters and supplies, etc.

Lewenstein, B. V. (2016). Can we understand citizen science? *Journal of Science Communication,* 15(1): 1-5, Editorial.

This editorial emphasizes the need for communication of results and data derived from citizen projects. The author maintains that the import of citizen science is not just to educate the populace and advance science, but to enhance our citizenship and societal engagement.

Lindenmayer, D. B. & Likens, G. E. (2009). Adaptive monitoring: a new paradigm for long-term research and monitoring. *Trends in Ecology and Evolution,* 24(9): 482-486. doi: 10.1016/j.tree.2009.03.005

The authors assert the importance of longitudinal research studies and data collection and "propose a new paradigm, adaptive monitoring." The premise is to use questions first to direct environmental research, analyze the functions of targeted ecosystems and steer scientific investigations to better focus on community needs.

Malone, J. (2002). *It Doesn't Take a Rocket Scientist: Great Amateurs of Science.* Hoboken, NJ: John Wiley & Sons, Inc. ISBN 0-471-41431-X.

Monograph documenting amateur scientists and their contributions.

Miller, T. S., Sherwood, D. A., Jeffers, P. M., & Mueller, N. (1998). Hydrology, Water Quality, and Simulation of Ground Water Flow in a Glacial Aquifer System, Cortland County, New York. *United States Geological Survey – Water-Resources Investigations Report 96-4255.* https://pubs.usgs.gov/wri/1996/4255/report.pdf

USGS Hydrology report of the sole source aquifer for Cortland County, NY. The Report includes information on physical geology of the region, land use, chemical evaluation of water quality, aquifer recharge capacity, and remediation efforts to the migration of trichloroethylene in the aquifer.

Mooney, C. (November 2011). The Truth about Fracking. *Scientific American.*

Journal article describing the process of natural gas extraction using the hydraulic fracturing technique also know as "fracking."

Neuhauser, A. (4 June 2015). EPA: Fracking Tainted Drinking Water, but Problems Not Widespread. *U.S. News and World Report.* https://www.usnews.com/news/articles/2015/06/04/epa-fracking-tainted-drinking-water-but-problems-not-widespread

News article reporting EPA assertion that drinking water supplies have been polluted by activities surrounding fracking procedures. Specifically, cracks/leaks in the concrete well bore casings have allowed fracking fluids and brine to migrate into drinking water wells/reservoirs.

New York State Department of Environmental Conservation. (2017). *Freshwater Macroinvertebrates of NY.* http://www.dec.ny.gov/animals/35772.html

An online photographic guide to benthic macroinvertebrates of New York State.

New York State Department of Environmental Conservation. (6 April 2017). WAVE Workshop: From Data to Action. Peebles Island State Park, Waterford, NY.

Panel presentations and discussion of the applications of WAVE data and analysis.

New York State Department of Environmental Conservation. (2009). *Owego Creek Watershed.* http://www.dec.ny.gov/docs/water_pdf/wisusqowego.pdf

Details of the Owego Creek Watershed as of 2009. A commentary of water quality sampling is provided as well as historical information regarding a major fish kill in 1980.

New York State Department of Environmental Conservation. (19 February 2017). Press Release: *NYS Department of Environmental Conservation and Tompkins County Health Department Statement on Salmon Creek and Cayuga Lake Water Quality Impacts.* http://www.dec.ny.gov/press/109305.html

Water Quality impact/alert regarding a manure discharge into Salmon Creek, north of Myers, NY. Due to a manure storage leak at the Sunnyside Farm dairy facility, emergency measures were taken to spread liquid manure on semi-frozen fields in winter. The resulting runoff entered Cayuga Lake via Salmon Creek.

New York State Department of Environmental Conservation. (2017). *Water Assessments by Volunteer Evaluators (WAVE).* http://www.dec.ny.gov/chemical/92229.html

also – NY-DEC Homepage http://www.dec.ny.gov/

State government website detailing the NYS-DEC WAVE benthic sampling program. Protocols, data forms, BMI photos, sampling selection maps, and results are provided.

New York State Department of Environmental Conservation – Division of Water. (18 April 2014). *Standard Operating Procedure: Biological Monitoring of Surface Waters in New York State.* Section 17.11 – Benthic Macroinvertebrate Species List. http://www.dec.ny.gov/docs/water_pdf/sop20814final.pdf

List of BMI species found in New York State with designations for Hilsenhoff's Biotic Index tolerance value.

Novak, J. D. and Gowan, D. B. (1984). *Learning How to Learn.* New York, NY: Cambridge University Press. ISBN: 0-521-31926-9 (paperback).

Epistemological learning theories are applied to science education. Authors introduce the idea of a "concept map" representing how informational connections are made in the process of learning. A graphic "epistemological Vee" features the path from theory to the 'actualization' of knowledge.

O'Connor, K. (17 February 2016). HIGH LEAD: Elevated in Caroline, Enfield school water. *The Ithaca Journal.* http://www.ithacajournal.com/story/news/local/2016/02/17/

Local newspaper report of Ithaca School District water testing results. Caroline Elementary School tests revealed that 35 of 91 samples had unacceptably high Lead (Pb) levels. Enfield Elementary School had 11 of 65 samples with high Lead levels. The actionable Lead level standard is 15 parts per billion (ppb).

Quammen, D. (2006). *The Reluctant Mr. Darwin: An Intimate Portrait of Charles Darwin and the Making of His Theory of Evolution.* New York, NY: W. W. Norton & Company. ISBN-13: 978-0-393-05981-6 (hardcover).

Biography of the life and times of Charles Darwin.

Ridlington, E. & Rumpler, J. (October 2013). *Fracking by the Numbers: Key Impacts of Dirty Drilling at the State and National Level.* Boston, MA: Environment America Research & Policy Center.

http://www.environmentamerica.org/sites/environment/files/reports/EA_FrackingNumbers_scrn.pdf

Research Report documenting the dangers of natural gas extraction using hydraulic fracturing procedures. Damage/pollution to water, air, and land is discussed. Drilling impacts for each state as well as information on the numbers of 'fracked' wells nationwide is provided.

Rutgers School of Arts & Sciences. (2016). Thomas A. Edison Papers: Thomas Alva Edison Biography. http://edison.rutgers.edu/biogrphy.htm

Online biographical information for Thomas Edison.

Science Communication Unit, University of the West of England, Bristol. (2013). Science for Environment Policy In- depth Report: Environmental Citizen Science. Report produced for the European Commission DG Environment, December 2013.

http://ec.europa.eu/science-environment-policy

Scholarly report prepared for the European Union regarding the current state/use of citizen science. A discussion of six citizen science programs sponsored by the European Environmental Agency is given. Projects include studies of birds and other vertebrates, invasive plant species, clam and oyster habitat restoration and climate predictions.

Seneca Lake Pure Waters Association. (3 March 2017). Seneca lake Pure Water Association Voices Concerns Over Reeder Creek at Seneca Army Depot. *FingerLakes1.com.*

https://senecalake.org/wp-content/uploads/2015/01/Army-Depot-Press-Release-March-3-2017.pdf

A grassroots citizen action group organized to protect and monitor Seneca Lake.

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B. V., Krasny, M. E. & and Bonney, R. (2012). Public participation in scientific research: a framework for deliberate design. *Ecology and Society,* 17(2): 29. doi: 10.5751/ES-04705-170229

Authors describe three citizen science (aka public participation in science research – PPSR) models and evaluate the degree to which outcomes are met in each. Models include: "contributory projects" where citizens are enlisted to collect/contribute data, "collaborative projects" that allow citizens both to collect and analyze data, and "co-created projects" that encourage public input on all phases of the research – including design, data collection, statistical analysis, interpretation and dissemination of results.

Sierra Club. (2017). *Explore, Enjoy, and Protect the Planet* (Home - webpage).

www.sierraclub.org

National environmental organization website.

Sierra Club – New York Water Sentinels. (2017). (Home – webpage).

https://nywatersentinels.org/

Website for the New York State Chapter of Sierra Club Water Sentinels. Includes login for both members (citizen scientists) - to post water quality data (i.e. conductivity, total dissolved solids) and for visitors to the website - to view data for sampled streams. Website also provides links to EPA water quality webpages, and Dickenson College ALLARM water monitoring resources.

United States Environmental Protection Agency. (Accession date 26 April 2017).

Superfund Site Information for Seneca Army Depot.

https://cumulis.epa.gov/supercpad/cursites/dsp_ssppSiteData1.cfm?id=0202425

Van Boven, L. & Gilovich, T. (2003). To Do or to Have? That is the Question.

Journal of Personality and Social Psychology, 85(6): 1193-1202.

doi: 10.1037/0022-3514.85.6.1193

An exploration of the relative value of material vs experiential gifts. Research survey results into the question of 'what makes people happy' indicates that experiences tend to generate happier, longer-lasting effects.

Wang, Yanan. (15 December 2015). In Flint, Mich., there's so much Lead in children's blood

that a state of emergency is declared. *The Washington Post.*

https://www.washingtonpost.com/news/morning-mix/wp/2015/12/15

News article detailing elevated Lead levels in Flint drinking water and children's blood.

Water Law for Activists: A Symposium Co-sponsored by the Sierra Club Atlantic Chapter and

the Cornell Environmental Law Society. (25 March 2017).

Ithaca, NY: Cornell Law School.

Symposium to educate/inform citizens of various assaults to water resources, the law and the public's right to clean water.

We Are Seneca Lake. http://www.wearesenecalake.com/

Grassroots citizen organization with a focus on the protection of Seneca Lake and the surrounding region. Because of grave risk to pollution and salinization of the lake activist/members strenuously oppose the commercial use of salt caverns beneath Seneca for proposed storage of liquefied petroleum gases (LPG).